

# ***NAVAL RESEARCH ADVISORY COMMITTEE***

## **Science and Technology for Modular Systems**

**Presentation to  
The Honorable John J. Young, Jr.  
ASN (RD&A)  
5 August 2004**

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## *Panel Membership*

**Ms. Teresa B. Smith – Chair**  
(Northrop Grumman)

**Dr. Walt Williamson – Vice-Chair**  
(Texas Christian University)

**Dr. A. Michael Andrews, II**  
(L-3 Communications, former DASA R&T)

**Dr. Gary W. Caille**  
(Georgia Institute of Technology)

**Dr. James Engelland**  
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**Dr. Eric Horvitz**  
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**Mr. Joseph Y. Rodriguez**  
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## *Terms of Reference*

- Review and assess *Navy systems engineering* efforts on programs of record and the extent to which *modular open systems, provisions for spiral upgrades, and S&T are factors in the requirements definition and acquisition processes.*
- Identify candidate *high-payoff S&T areas for modular development and horizontal integration*; and assess the opportunities for S&T engagement with systems engineering efforts.
- Where appropriate, recommend *guidelines for structuring modular S&T* initiatives that would enable utilization of results in multiple platforms/missions packages.
- Recommend changes required to improve *the interface between Navy's S&T planning and acquisition processes.*

## *Approach*

- Reviewed selected *programs of record* for modularity implementation
  - *Types* of modularity and drivers
  - *Degree* of modularity versus integration
  - *Methodology* (systems engineering and procurement requirements) used to define modularity
  - *Spirals* – provisions to incorporate future capabilities (S&T)
  - *Benefits* – business and operational cases
- Baselined *commercial and defense industry* (U.S. and International) for modularity drivers, business models, implementation methodologies and benefits
- Reviewed *systems engineering practices*, especially regarding modularity
- Surveyed *literature* for implementation methodologies, business drivers, metrics for measuring success and prior Government/Industry studies



## *Briefings Received*

### Programs

- Virginia Class Subs
- SSGN Conversion
- ARCI
- CVN-21
- DD(X)
- MMA
- J-UCAS
- JTRS
- ONR FNC
- LCS Seaframe
- LCS Mission Modules
- Integrated Deepwater System
- FCS System Analysis (Sandia)
- HSV-2
- X-Craft

### Systems Engineering/Other

- NAVSEA 05
- ASN RDA Deputy CHENG
- Total Open System Architecture
- PEO IWS Open System Architecture
- Navy Acquisition Management
- NPS/Meyer Institute of Systems Eng.
- MIT Lean Initiative
- AF Systems Engineering Forum
- OSD Open Systems Joint Task Force
- OUSD (AT&L) – Defense Systems

### Guidance

- CNR
- DASN (RDT&E)
- PEO Ships

### Industry

- Boeing
- IBM
- L3 Communications
- Lockheed Martin
- Microsoft
- Northrop Grumman
- Rockwell Collins

### International

- Ericsson
- HDW
- Naval Team Denmark
- Thales

## *Executive Summary*

- Modularity concepts are intuitively simple, but multi-faceted, complex to implement effectively.
- Navy programs delegate modularity implementation to primes/LSIs without guidelines - resulting in questionable benefits and contractor stovepipes.
- Navy should perform systems engineering and set procurement guidelines to effectively implement modularity horizontally; *the Navy should not abdicate the systems engineering responsibility.*
- Navy S&T Community should support the introduction of modular systems into Navy programs by developing capabilities to decompose complex systems, experimenting with modular concepts to support acquisition spirals, and developing M&S tools to enable system of systems engineering analysis.



## *Bottom Line, Up Front*

**The real issue is a lack of a Navy-wide Systems Engineering & Analysis Process**

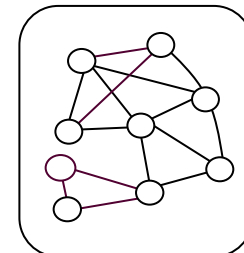
Systems Engineering & Analysis applied horizontally across programs enables determination of appropriate modularity

**Systems Engineering**

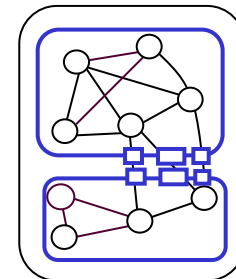
Is a top-down, comprehensive, interactive and recursive system synthesis & analysis process; applied through all stages of development and sustainment

**Integrated**

An architectural framework where most system functions are mapped to single components. Components have high degrees of interdependency and non-standard interfaces.

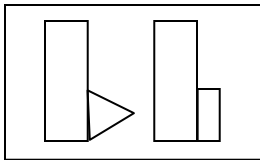
**Modular**

An architecture where system functions are partitioned into elements consisting of various components. These elements have standard/defined interfaces and minimal interdependencies in the overall system.

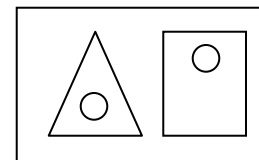
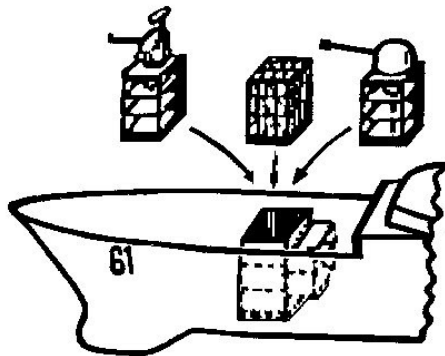


# Background

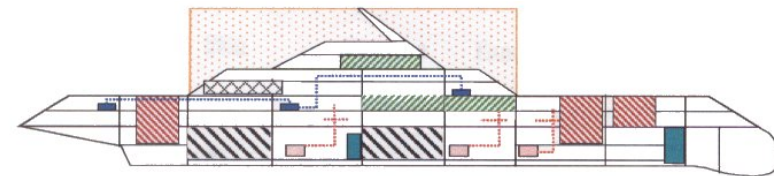
## Types of Modularity



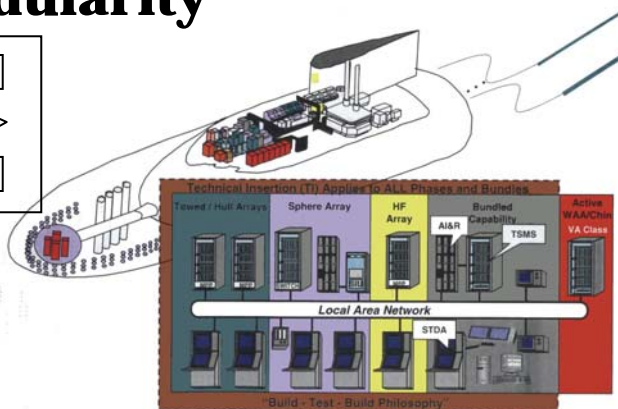
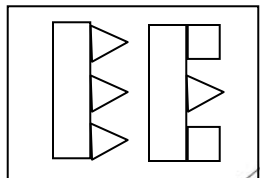
**Capability Swapping  
Modularity -  
Mission Packages**



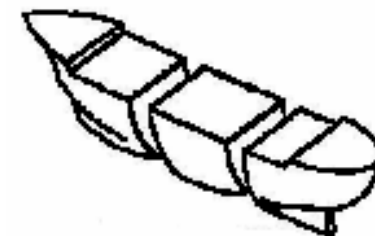
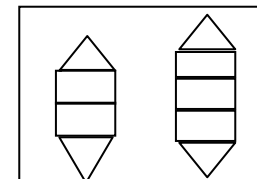
**Component  
Sharing  
Modularity**



**Bus Modularity**



**Construction/Design  
Modularity**





## *Background*

# *Modularity: Why or Why Not?*

### Drivers

- Technology Refresh
- Interoperability
- Increased Readiness
- Mission Reconfiguration
- Capability Upgrades
- Construction/Manufacturing
- Design Re-use & Qualification
- Logistics & Maintainability
- Training
- Navy Total Ownership Cost

### Tradeoffs

- Performance
- Development Risk
- Flexible & Enhanced Operational Capabilities
- Manpower & Skills
- Schedule/Time
- Economies of Scale
- Best of Breed Technology
- Acquisition Cost
- Physical (size, weight, power)

**Decisions for modularity require understanding operational/business drivers and tradeoffs**

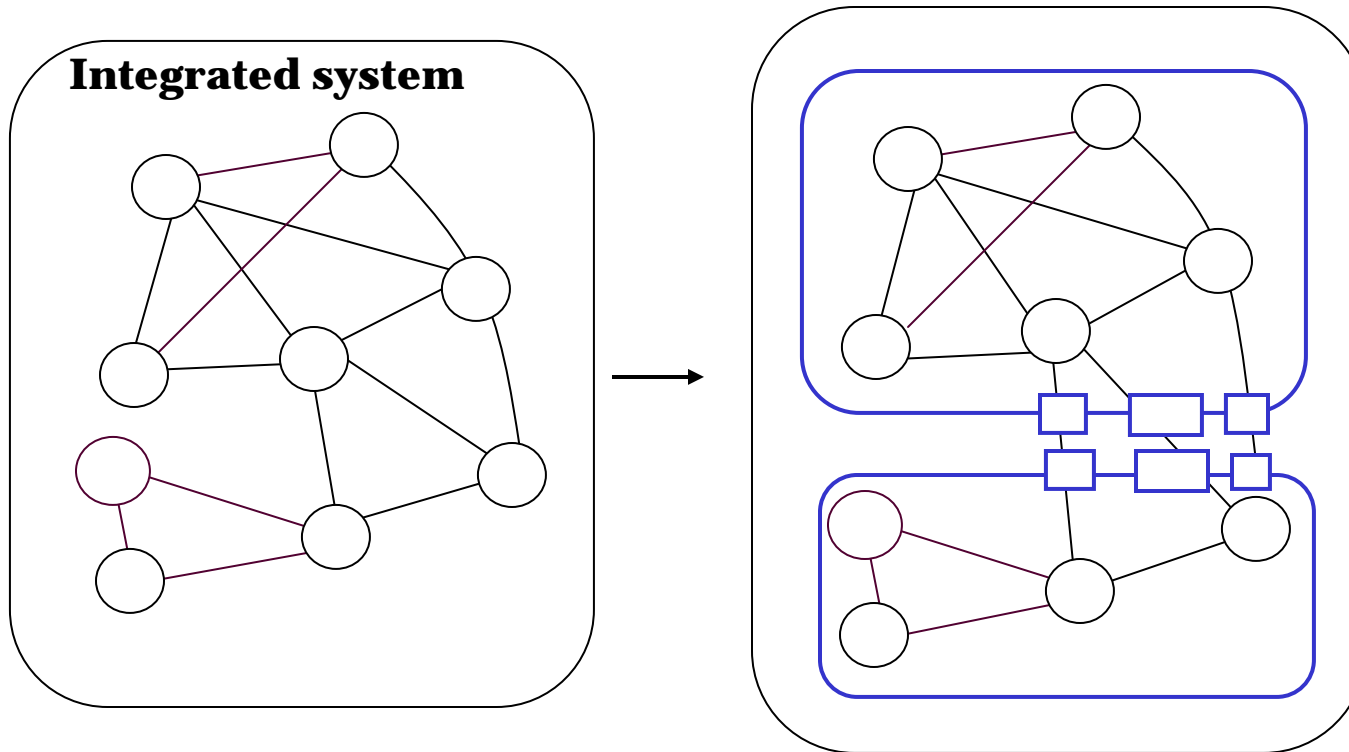
# Background

## Evaluating Modularity Tradeoffs

- What are good decompositions?

- Introduction of multiple considerations
- Understanding tradeoffs

**“Minimize interface complexity for ease of mission reconfiguration”**

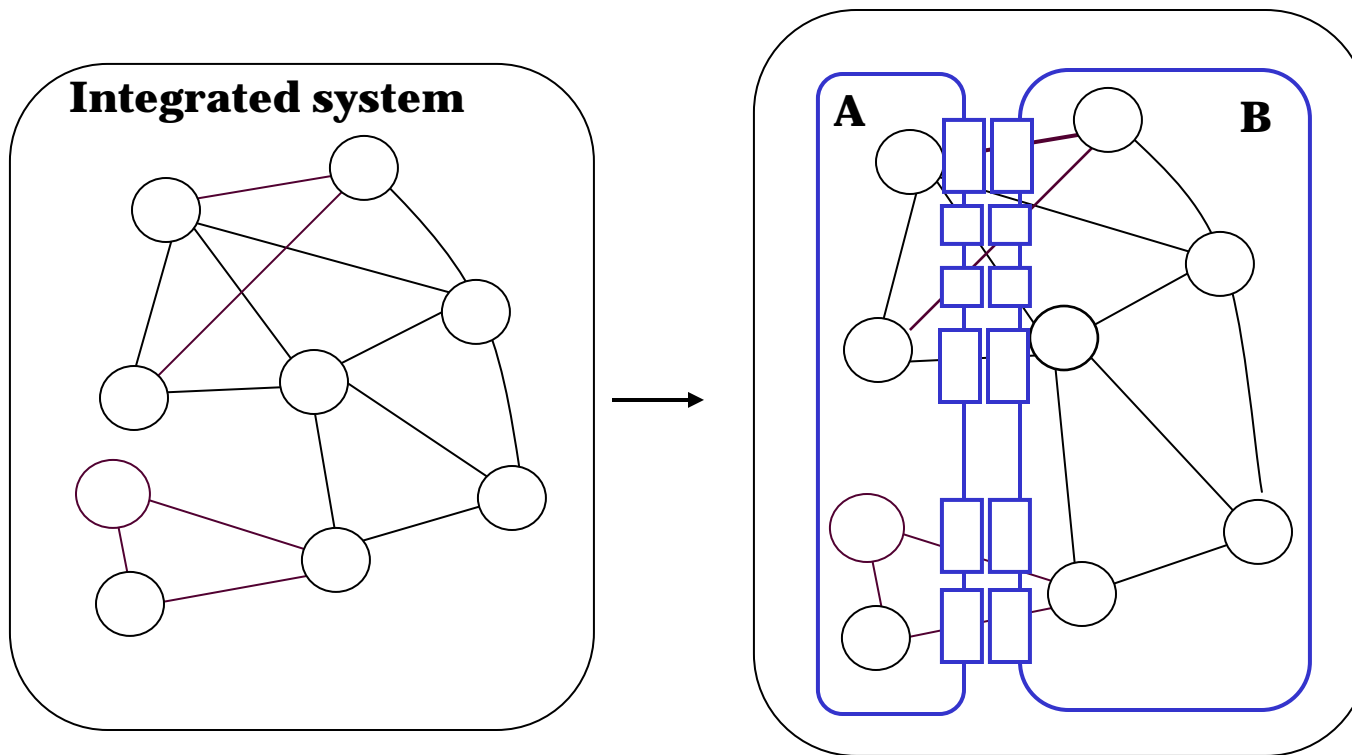


# *Background*

## *Evaluating Modularity Tradeoffs*

- What are good decompositions?
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  - Understanding tradeoffs

**“Prepare for technical refresh of A”**



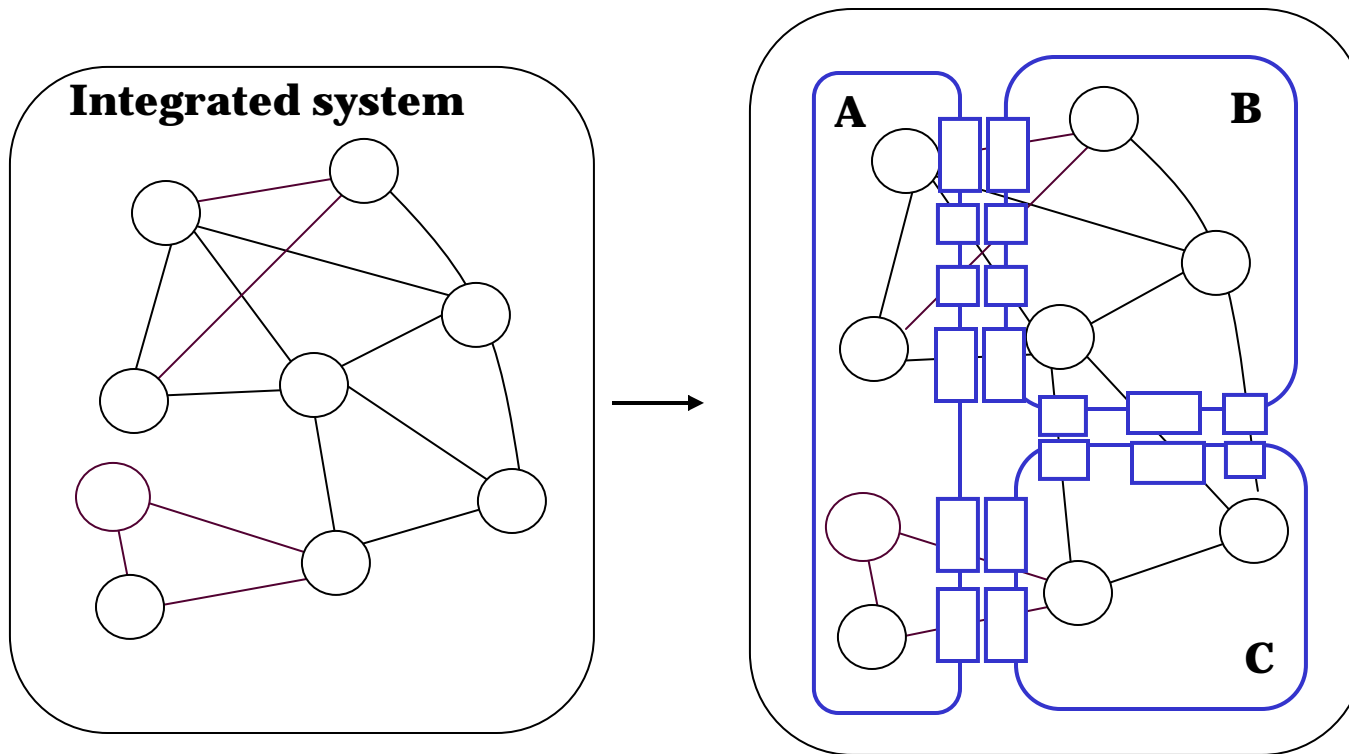
# Background

## Evaluating Modularity Tradeoffs

- What are good decompositions?

- Introduction of multiple considerations
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**“Prepare for technical refresh of A,  
and ready for failure of B”**



## *Pillars of Modular Systems*

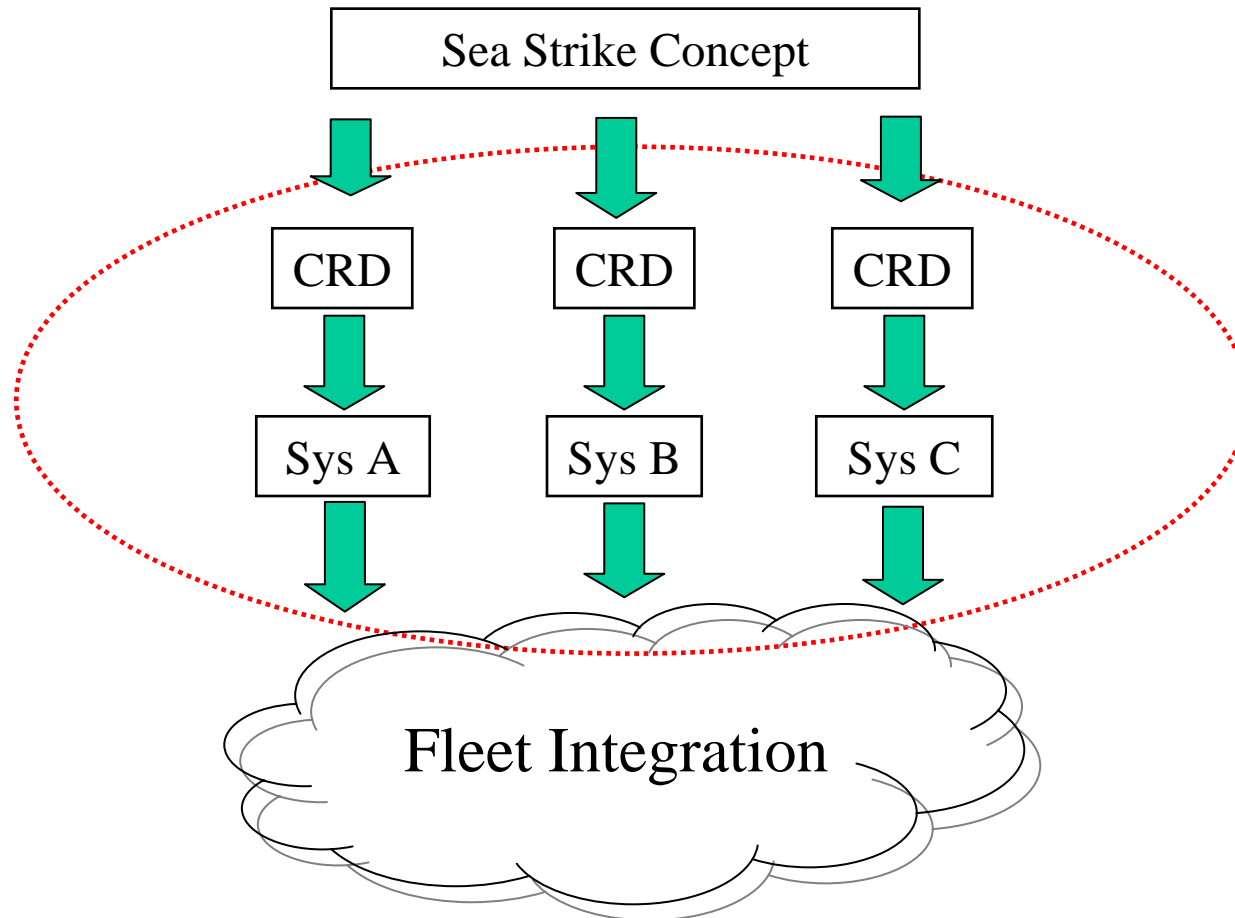
- **Systems Engineering**
- **Standard Interfaces**
- **Open System Architecture**

**Systems Engineering Drives Standards  
and Open System Architecture**



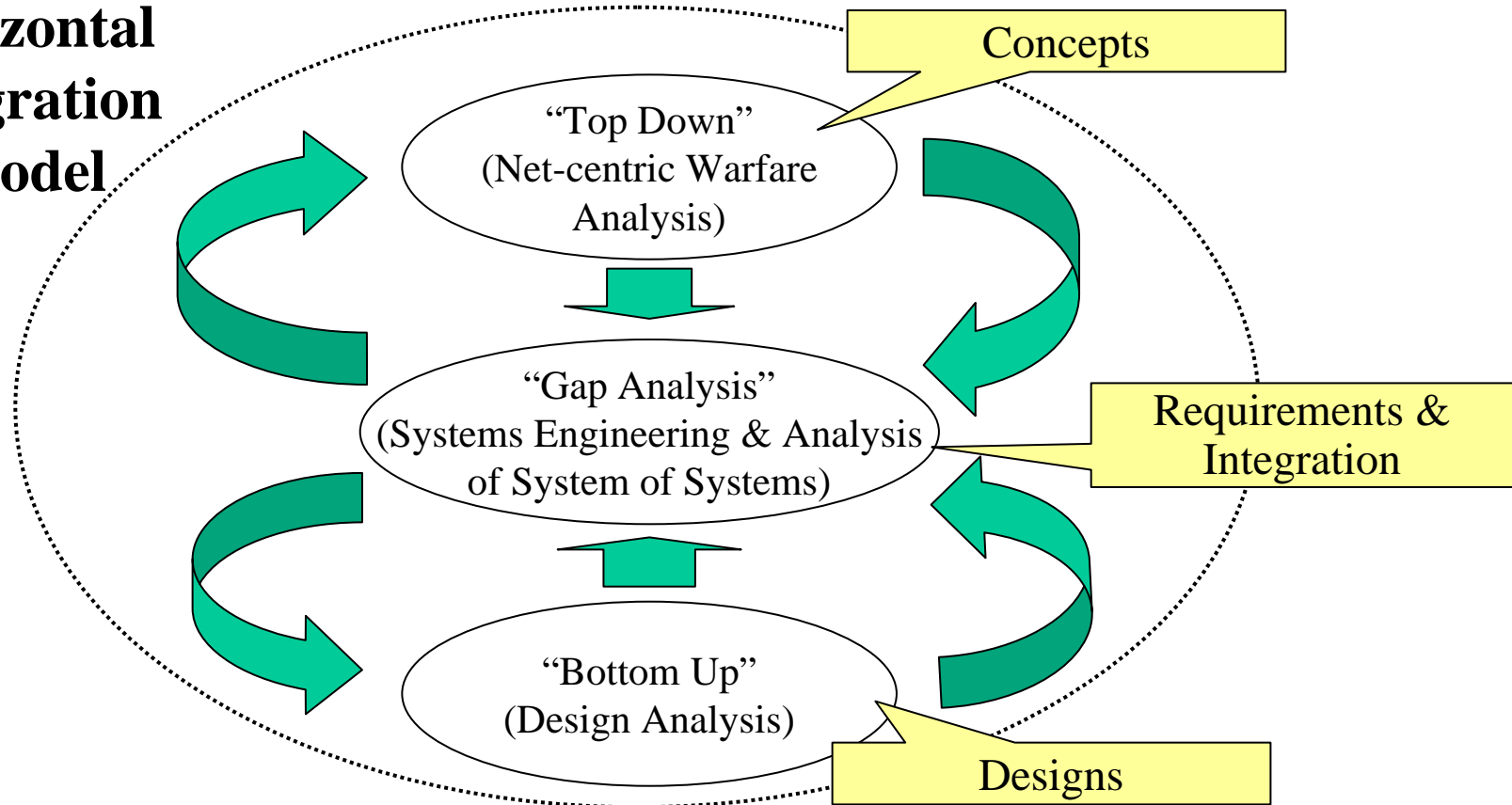
# *Background Systems Engineering*

## Platform/Program Model



# *Background Systems Engineering*

## **Horizontal Integration Model**



**Modularity for System-of-Systems Require Horizontal Approach to SE**

# Findings

## *Navy Program Findings*

- No actionable *policy, guidance, definitions, or principles* for modularity
- Shortage of *systems engineers* and lack of experience with modularity

### **Decision Process**

- *Motivators* for modularity not understood or articulated
- Inconsistent *system analysis* (if any), program/platform centric, done by primes

### **Acquisition Implementation**

- LCS, SSGN, and ARCI reflect transformational use of modularity
- In general, programs have delegated decision responsibility for modularity to primes without guidelines or incentives
- No serious commitment to spiral development observed; S&T community largely decoupled
- Impact of modularity on T&E, training, and logistics not well understood

## *Navy Program Findings*

### **Examples of Best Practices**

- LCS, SSGN: Navy taking responsibility for upfront SE
- ARCI: good use of modularity, spiral development, commercial standards, & technology to enhance capability
- Virginia Class: good example of benefits of modular construction
- X-Craft and HSV2 potential test beds for SE and operational mission module evaluations

### **Areas for Improvement**

- UUVs (approximately 70 types): lack of modularity, policy, guidance, and standards
- MMA: program office and prime have different visions
- MMA, ACS, BAMS, J-UCAS: minimal horizontal systems engineering
- LCS and Deepwater: MOU in place; questionable commitment
- DD(X), CG(X), CVN21: technology sharing opportunity
- FORCEnet: System of Systems Engineering an absolute requirement

## *U.S. Industry Findings*

- No common definitions or standards for modularity (*Defense*)
- Company interests dominate modularity decisions (*Defense*)
- Need for Systems Engineering recognized, not uniformly implemented, and shortage of expertise (*Defense & Commercial*)
- Software an enabler for open-system architectures and modularity (*Defense & Commercial*)
- Low percentage of software re-use; high opportunity for cost savings (*Defense & Commercial*)

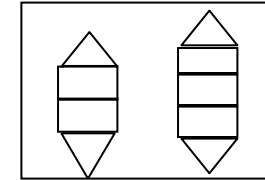
### **Defense Industry Specifics**

- *Capability Swapping Modularity/Mission Packages* - industry not developing unless directed by government
- *Construction/Design Modularity* – both government and industry in harmony
- *Bus Modularity* - commercial companies ahead of defense in implementation
- *Component Sharing Modularity* - defined by company business models not by customer

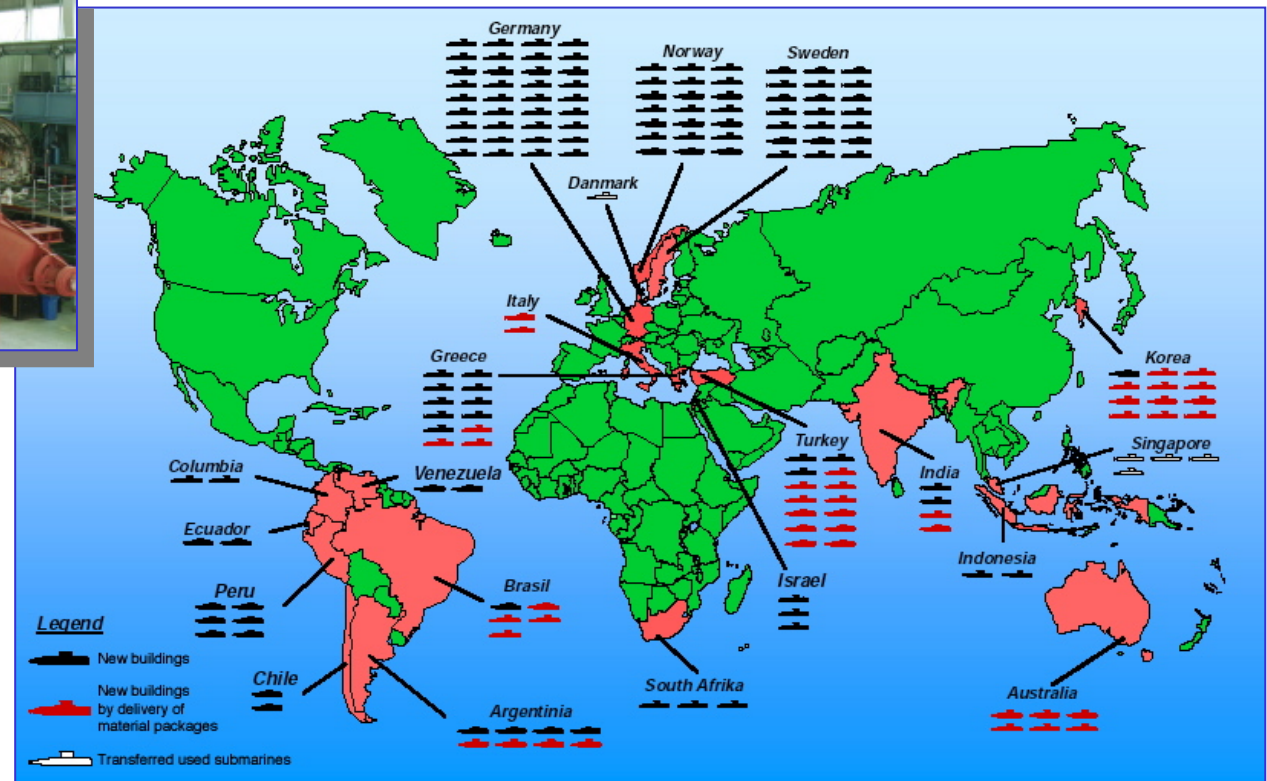
## *International Findings*

- Global Market Drives Business Behavior
- Effective Joint Government-Industry Collaborations
  - Naval Team Denmark
- European defense products reviewed incorporate more modularity than U.S.
  - Systems Engineering used to determine type and degree of modularity

## International Findings

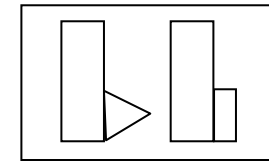


Specific Examples	Primary Motivation	Approach
<b>HDW / small submarines</b> <i>(Construction Modularity)</i>	<ul style="list-style-type: none"> <li>Custom offerings to diverse market (design reuse)</li> <li>Construction efficiency</li> </ul>	<ul style="list-style-type: none"> <li>Modular hull sections</li> <li>Optional capabilities</li> </ul>

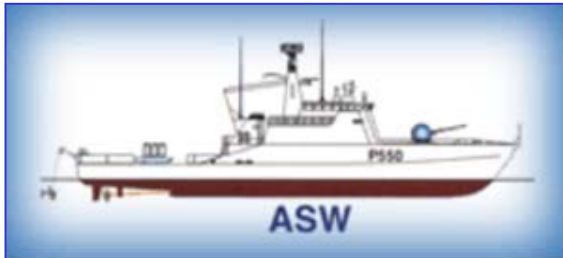




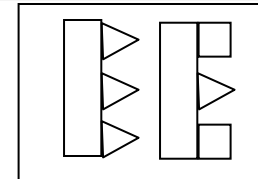
# International Findings



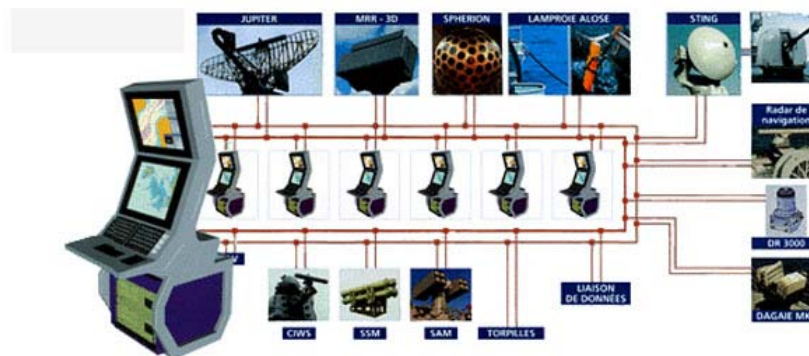
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Naval Team Denmark / Stanflex ( <i>Mission Pkg Modularity</i> )	<ul style="list-style-type: none"> <li>• Mission reconfiguration</li> <li>• Increased readiness</li> </ul>	<ul style="list-style-type: none"> <li>• System-level mission packages</li> </ul>



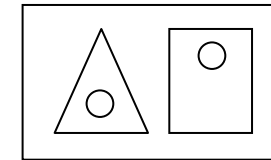
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Thales / TACTICOS TERMA / T-Core® Thales / UBMS ( <i>Bus Modularity</i> )	<ul style="list-style-type: none"> <li>• Capability upgrades</li> <li>• Enable market penetration</li> <li>• Design reuse</li> <li>• Scalability</li> </ul>	<ul style="list-style-type: none"> <li>• Open Architecture infrastructure</li> </ul>



# International Findings



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Thales / Sea Guardian ( <i>Component Modularity</i> )	<ul style="list-style-type: none"> <li>• Fixed &amp; mobile implementations</li> </ul>	<ul style="list-style-type: none"> <li>• Sensor subsystem modularity</li> <li>• Integration at combat system level</li> </ul>



## *Systems Engineering Findings*

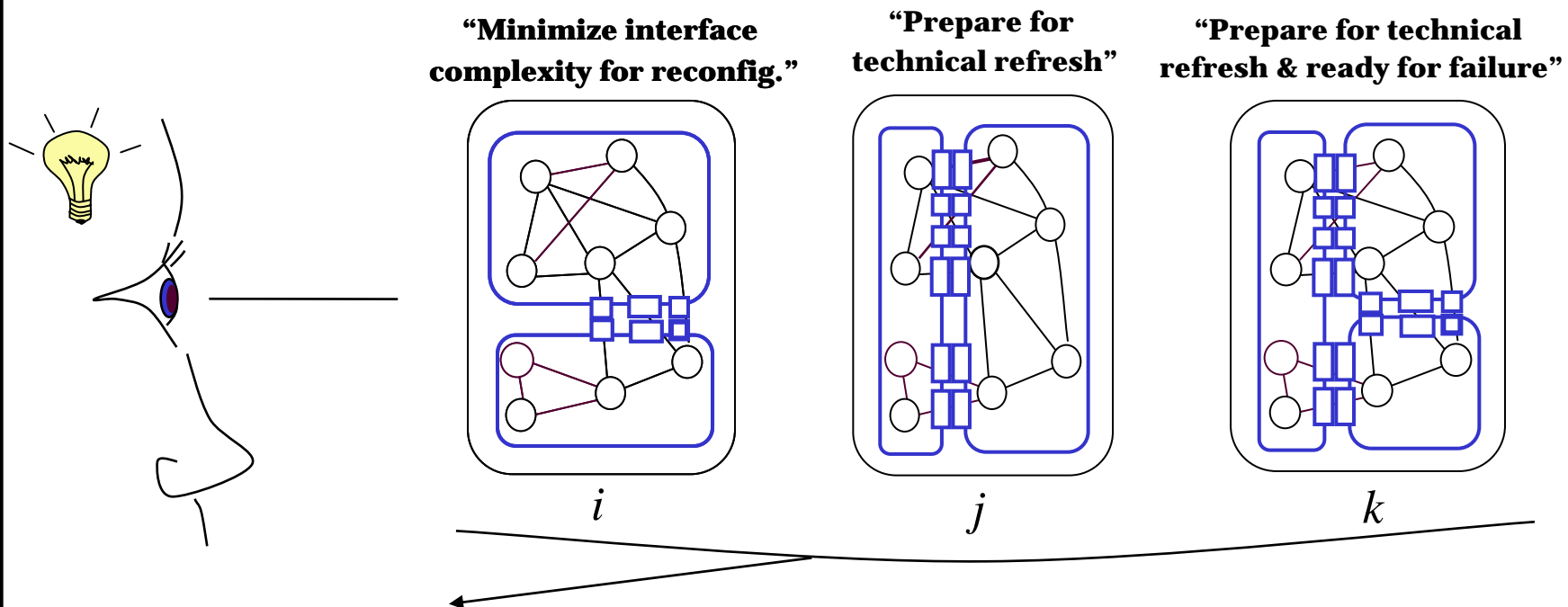
- *Processes* - poorly defined, inconsistently implemented
- *Systems Engineers* - significant deficiencies in numbers, education and experience – Government & Defense Industry
- *No horizontal integration* - Systems engineering, when performed, at platform/program level and stove-piped
- *Systems engineering tools* - no comprehensive, standard set
- *S&T* - decoupled from systems engineering enterprise
- *NPS* - has systems engineering curriculum, performs military oriented systems engineering studies; Navy needs more thoughtful process to determine future assignments of graduates

## *Literature Survey Findings*

- Limited information on DoD implementations of modularity
  - Critical military factors (e.g. mission flexibility, acquisition tradeoffs) not considered in modularity optimization
  - Some studies related to systems engineering and modularity to Navy ships
  - No formal DoD analysis with explicit focus on S&T for modularity and systems engineering
- Several recent articles and reports have explored *methodologies for design and evaluation of modular systems*
  - Some preliminary work defining degrees and types of modularity
  - Focus on *commercial applications*
  - More mature for software than hardware – but still largely heuristic

# Needed: Tools and Methodologies for Evaluating System Decompositions

- Capture, represent, analyze *multiple concurrent objectives*
- Optimization for benefits—*quantitative or qualitative*



Utility(Partition *i*) =

$$f [ \text{cost}^s(\text{refresh}), \text{cost}^s(\text{interfaces}), \text{cost}^s(\text{failure}), \text{cost}^{avail}(\text{failure}), \dots ]$$

## *Summary Findings*

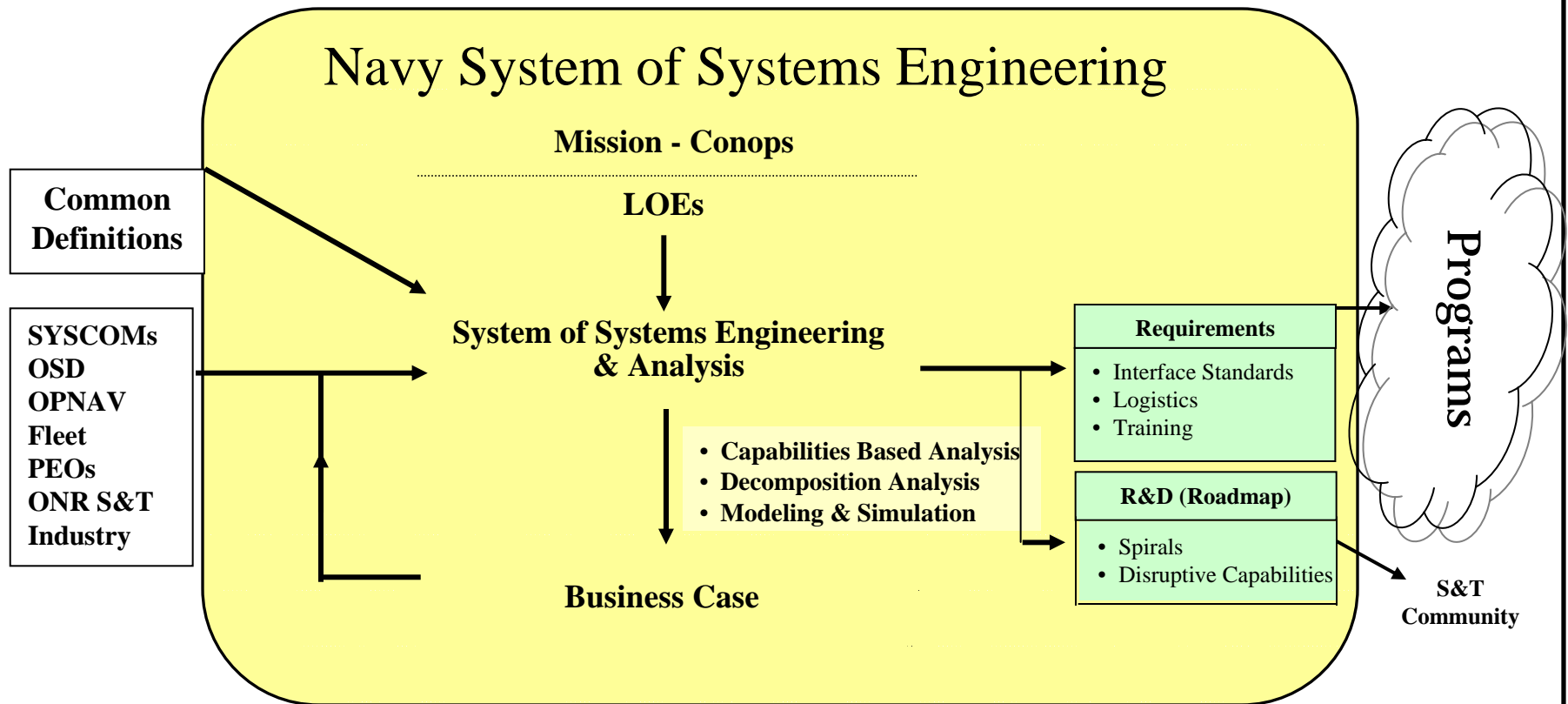
- *Navy Programs* – implementation of modularity delegated to primes; no horizontal systems engineering
- *U.S. Defense Industry* – systems engineering and modularity not uniformly applied within programs
- *International industry* - ahead of the U.S. defense industry in judicious use of modularity
- *Systems Engineering* – systems engineering fundamental to implementing modularity but current practice inadequate
- *Literature Survey* – early work on methodologies for decomposition of systems

## *Recommendations*

- ASN (RD&A), with VCNO and ACMC, take lead in *developing a Naval-wide System-of-Systems Engineering function* that follows a top-down, interactive, and recursive system synthesis & analysis process to define requirements.
- CNO & CMC *identify driving factors* for modularity and develop Naval policy and guidance for implementing modularity.
- CNR *lead as technology change agent* for (1) development of methodologies for understanding complex systems, enabling modular design; (2) experimentation with modular systems to support acquisition spirals (starting with LCS); (3) development of M&S tools to enable system of systems engineering analysis; and (4) development of advanced concepts & tools for software optimization & re-use.



# Requirements Community Needs to Drive Modularity Guidelines Horizontally



Establish Navy Systems Engineering & Analysis Function

## *Recommendations*

- ASN (RD&A), with VCNO and ACMC, take lead in *developing a Naval-wide System-of-Systems Engineering function* that follows a top-down, interactive, recursive, system synthesis & analysis process to define requirements.
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- CNR *lead as technology change agent* for (1) development of methodologies for understanding complex systems, enabling modular design; (2) experimentation with modular systems to support acquisition spirals (starting with LCS); (3) development of M&S tools to enable system of systems engineering analysis; and (4) development of advanced concepts & tools for software optimization & re-use.

## *Conclusions*

**The time is right to harvest value from modularity through disciplined Systems Engineering**

**Implementing System of Systems Engineering and adopting modularity effectively can result in:**

- Flexible and interoperable warfighting systems that can better address an uncertain future
- Ability to cope with limited resources

## *Summary Findings*

- *Navy Programs* – implementation of modularity delegated to primes; no horizontal systems engineering
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- *International industry* - ahead of the U.S. defense industry in judicious use of modularity
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